Advanced Inductor Materials for Power Electronic Applications

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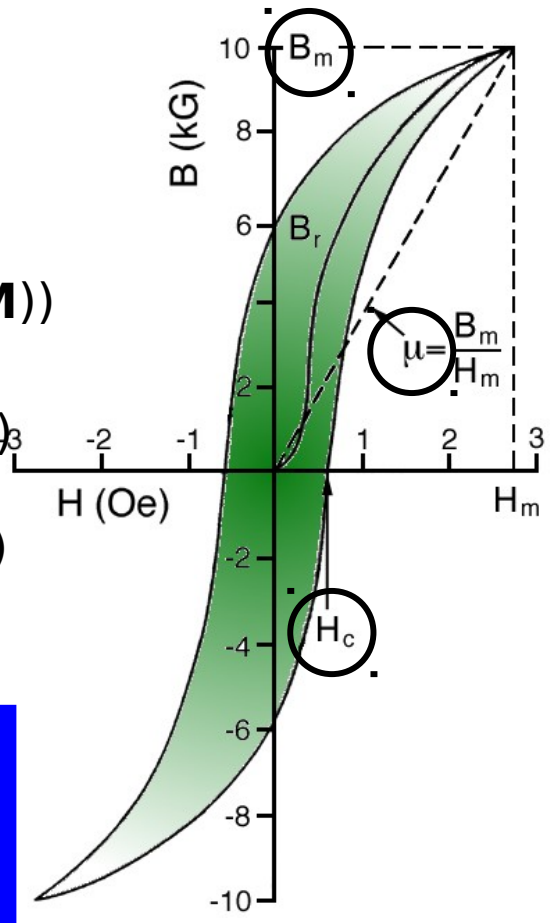
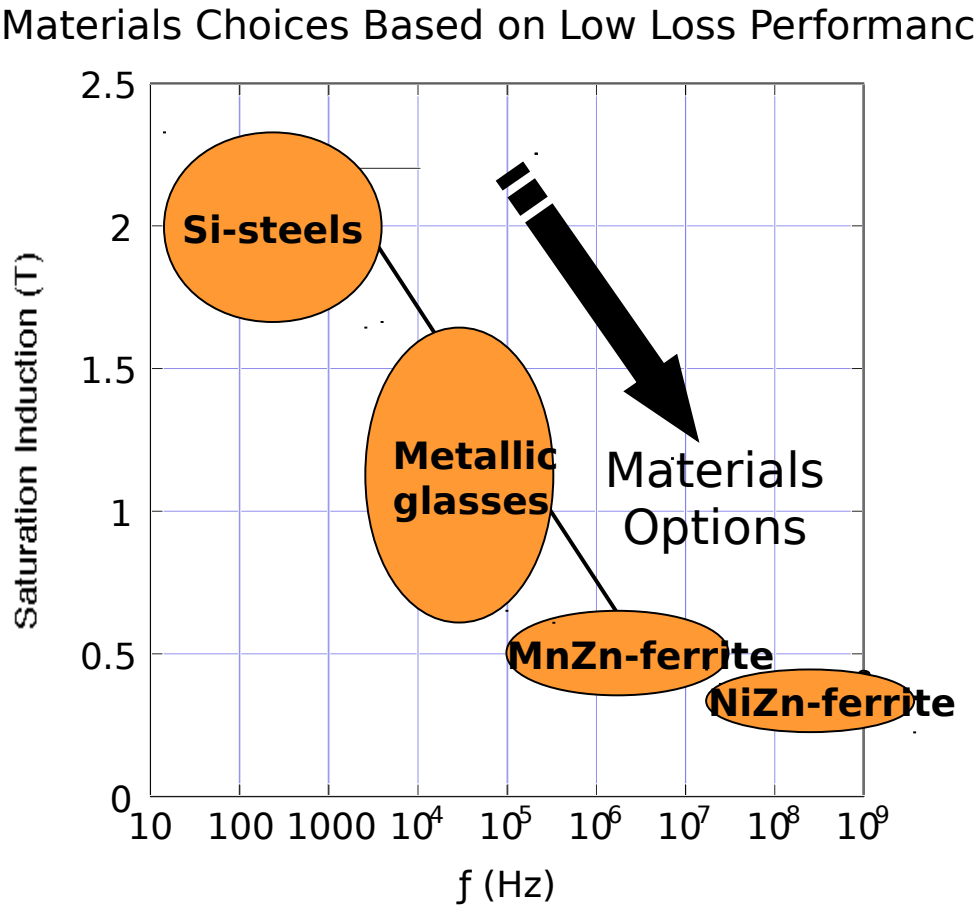
Inductor Material Needs

Functional Properties	**Material Properties**
Load (max I).....	Induction, ($B_s=\mu_0(\mathbf{H}+\mathbf{M})$)
Hysteretic losses (dc)	Coercivity (H_c)
Conduction losses (ac).....	Electrical resistivity (ρ)
Permeability.....	Magnetostriction (λ)
Operational temperature ..	Curie Temperature (T_c)
	(Microstructure stability)

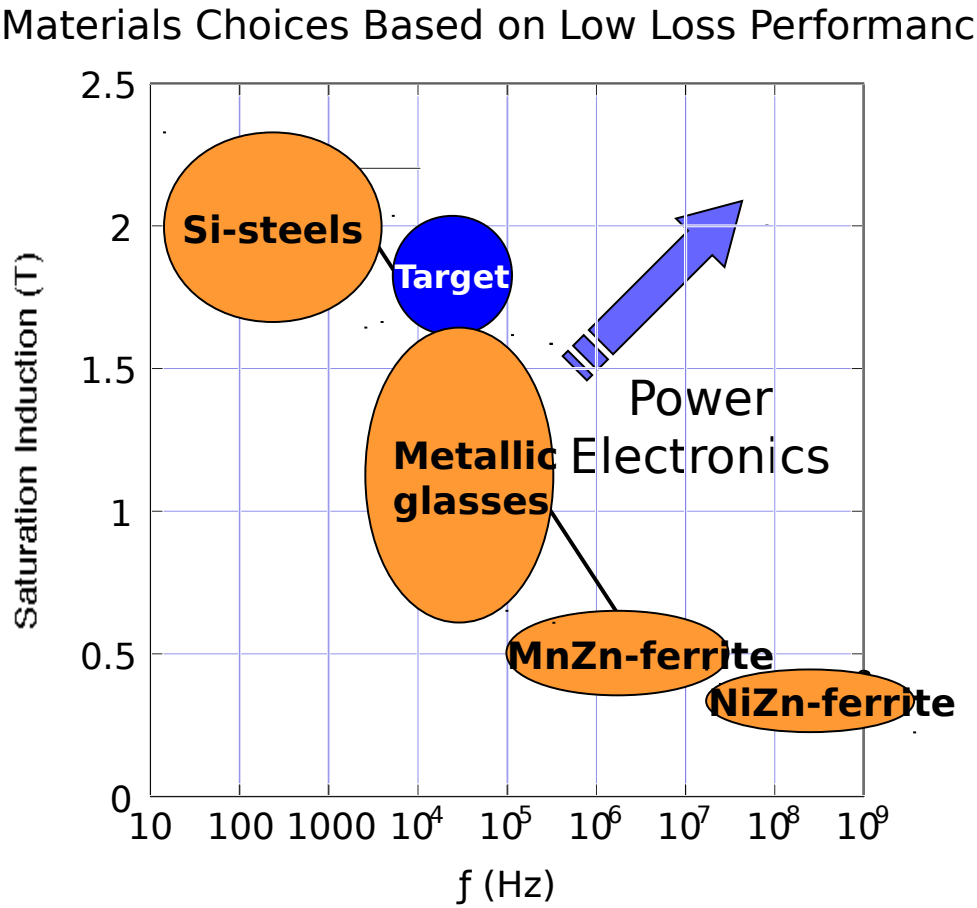


Goals—
Develop inductor materials with high magnetization, low core loss, and high operating temperature.

Power electronics present and future



Power electronics present and future



Nanocrystalline Inductor Materials

Composition

$(Fe, Co, Ni)_{89-x}Zr_7B_4Cu_x$

1% Cu often needed for nucleation of nanophase

Ferromagnetic transition metals to enhance M_s and T_c

Class stabilizers at 11% vs 20% in Metglasses™

Metglasses™ (amorphous alloys)

Composition

$(Fe, Co, Ni)_{80}(Si,B)_{20}$

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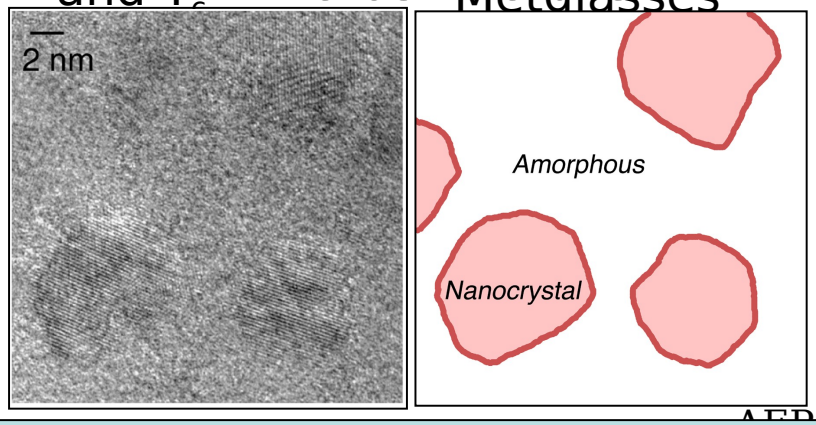
Microstructure



M. A. Willard, J. H. Claassen, R. M. Stroud, and V. G. Harris:

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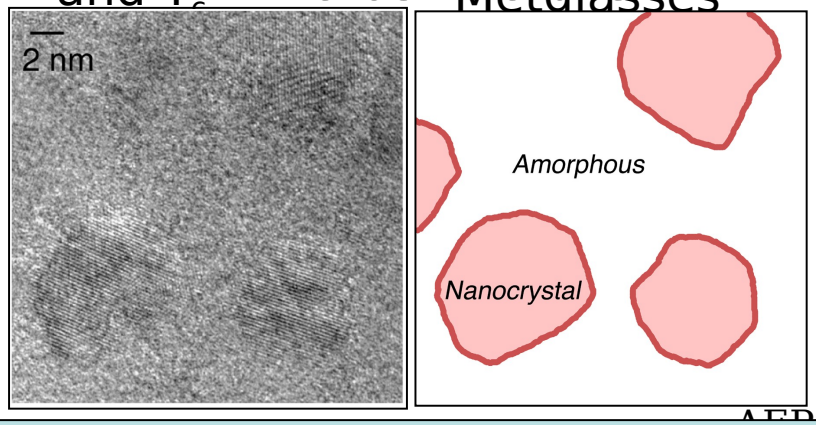

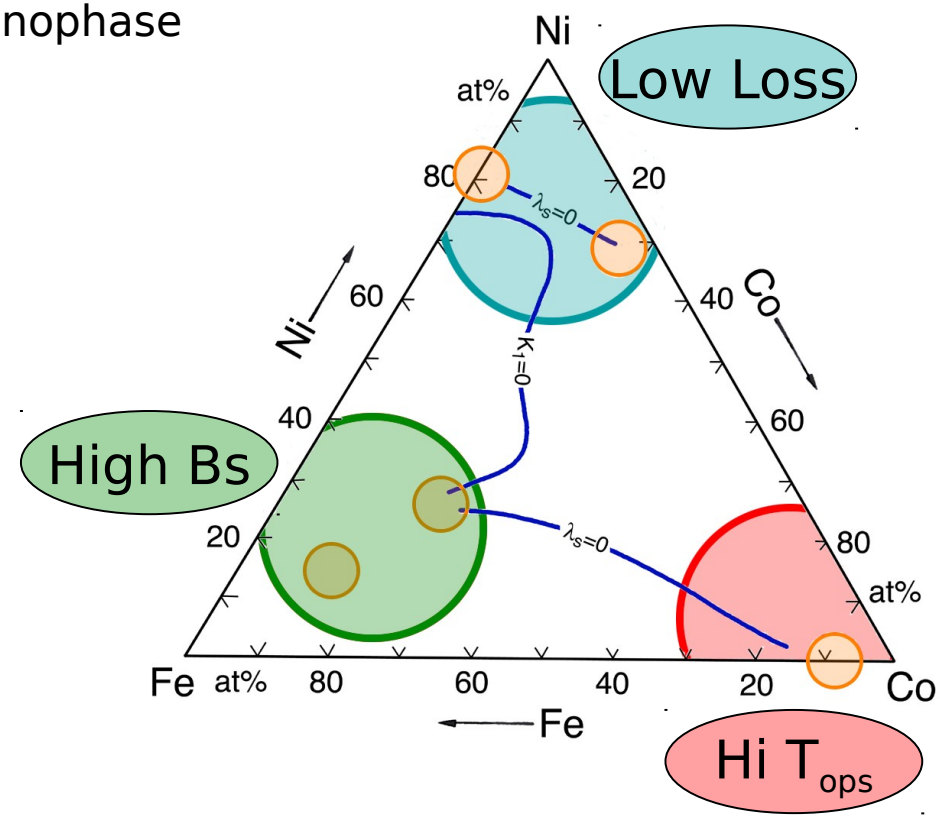

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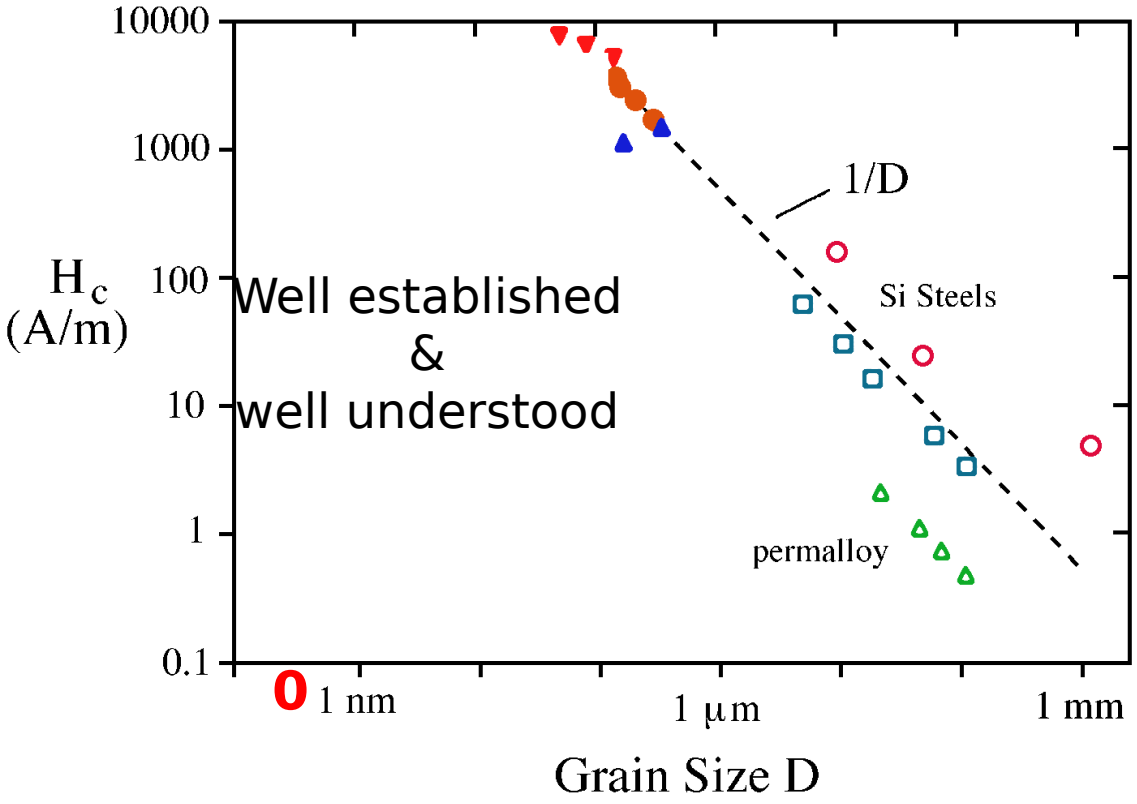
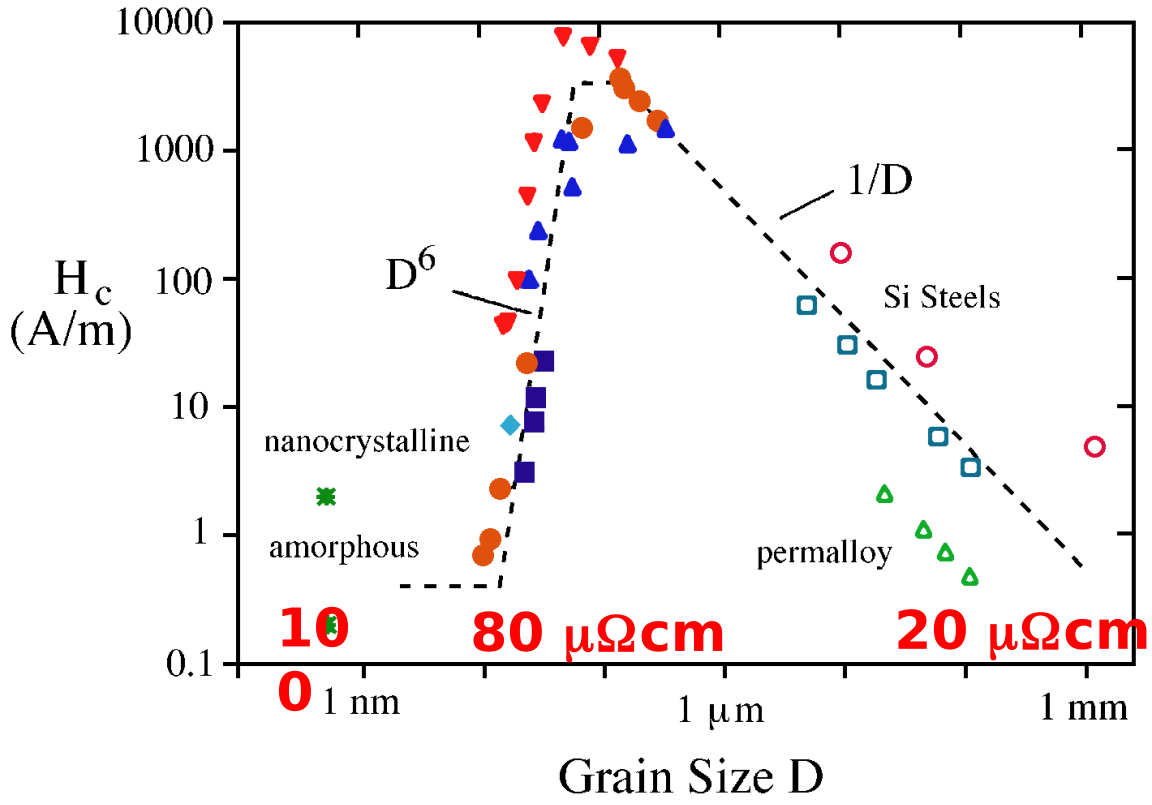
Role of morphology in soft magnetic properties



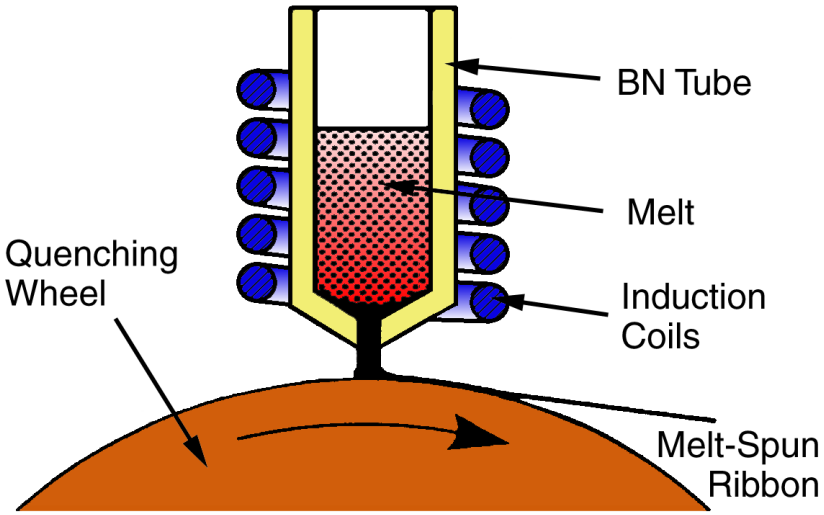
D6 data

Role of morphology in soft magnetic properties

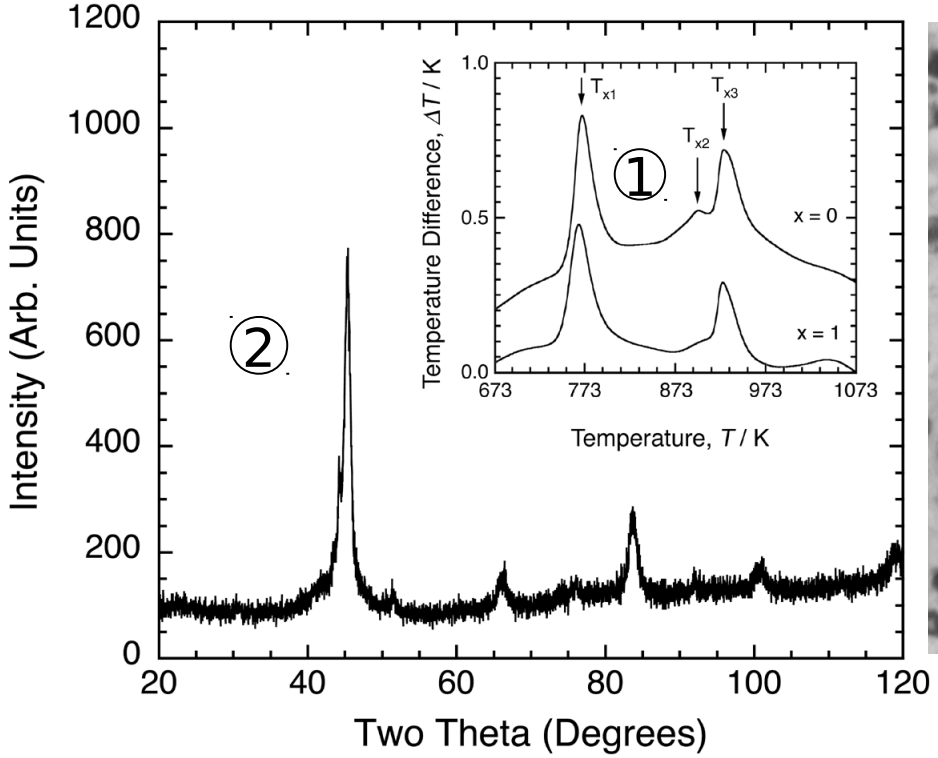


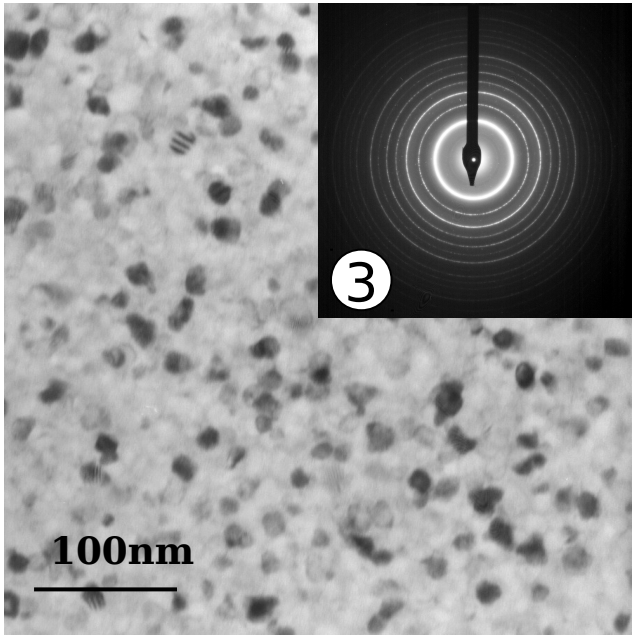
Processing of Nanocrystalline Alloys

- Arc melting
  - Forms homogeneous ingot
- Melt spinning
  - Forms amorphous precursor alloy ribbon
- Annealing in Inert Gas
  - Forms nanocrystalline alloy



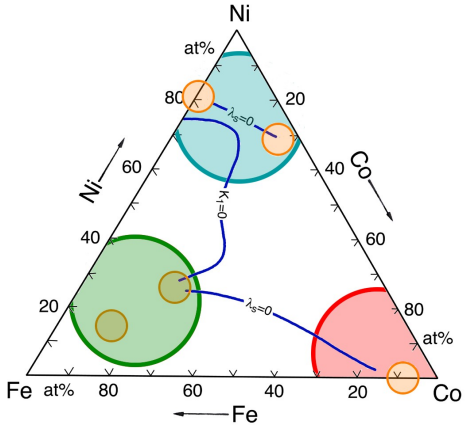
Post-Processing Optimization



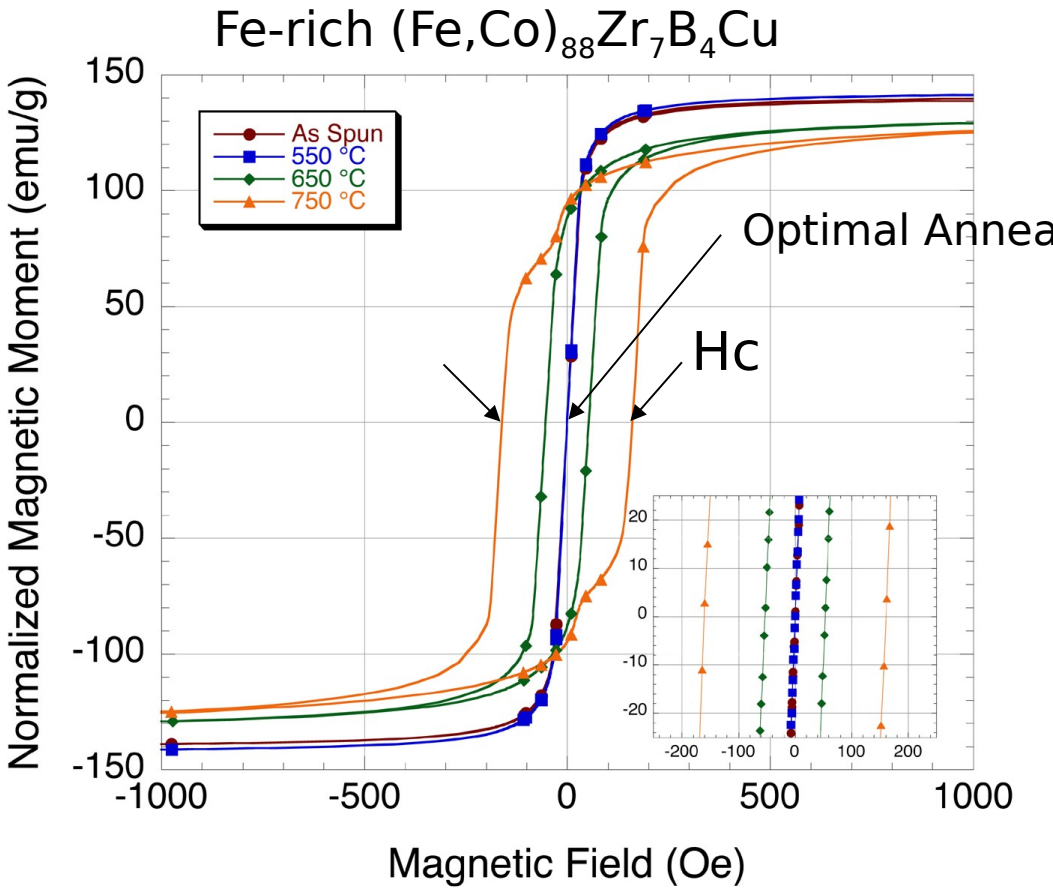


M. A. Willard, J. H. Claassen, R. M. Stroud, and V. G. Harris: *J. Appl. Phys.* **91** (2002) 8420.
M. A. Willard and V. G. Harris: *J. Metals* (Mar. 2002) 44.

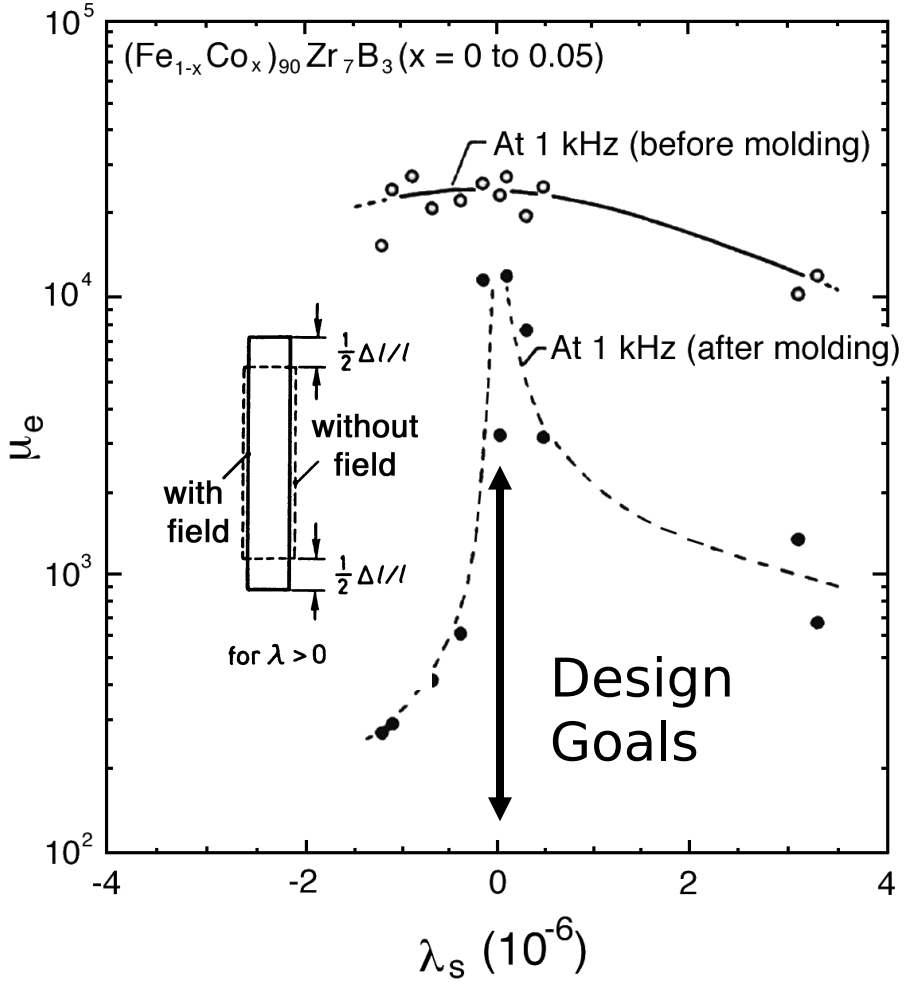
High Magnetization Alloys



- 14% higher magnetization than comparable amorphous alloy
- with 50% reduction in the magnetostriction coefficient
- (Fe, Ni, Co)-based alloys
  - Saturation magnetization of 1.77
  - Magnetostriction coefficient of 13 ppm

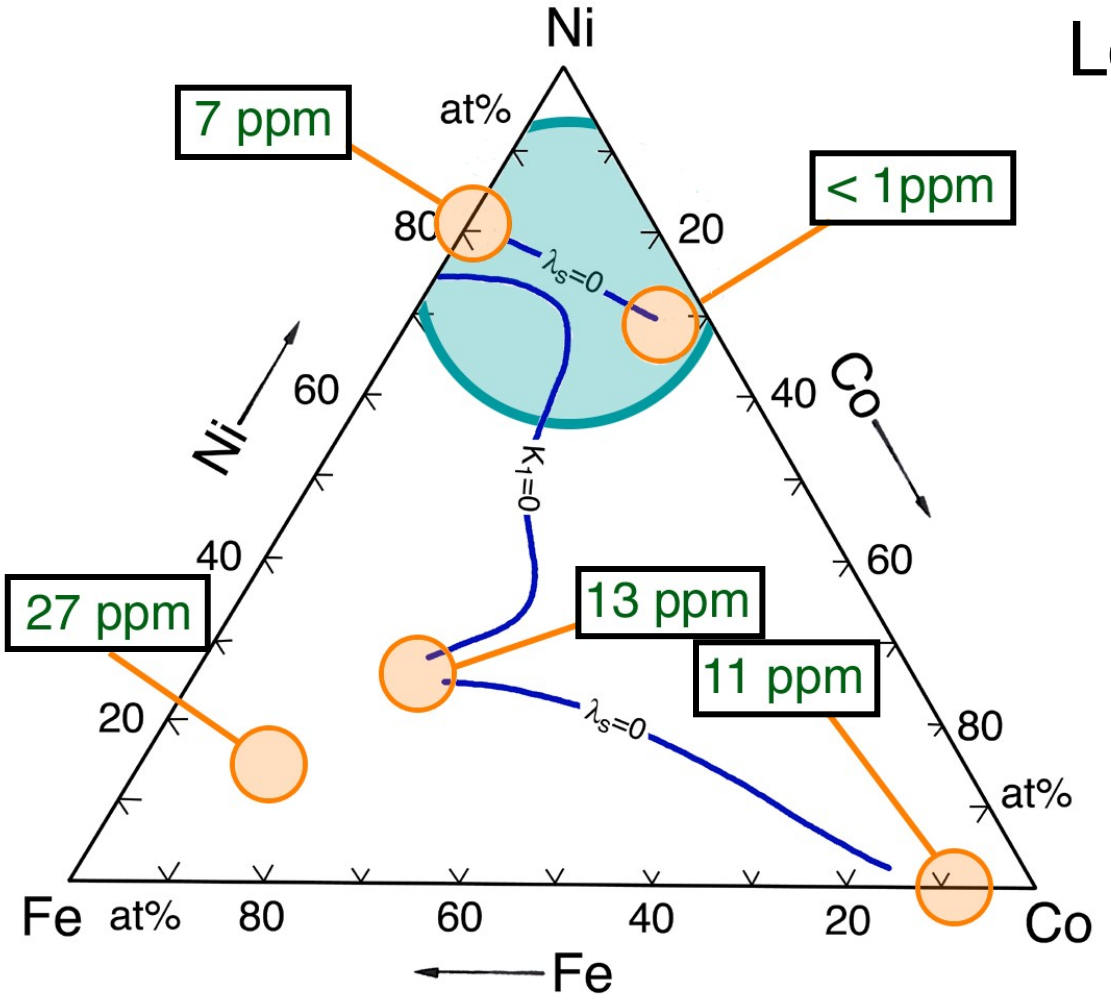


M. A. Willard, J. H. Claassen, R. M. Stroud, T. L. Francavilla, and V. G. Harris: *IEEE Trans. Mag.* **38** (2002) 3045.



- Magnetostriction
  - Coupling of atomic lattice to magnetic lattice
  - Source of loss for soft magnets resists spin rotation
- Low λ_s provides high permeability under strain (or vibration)

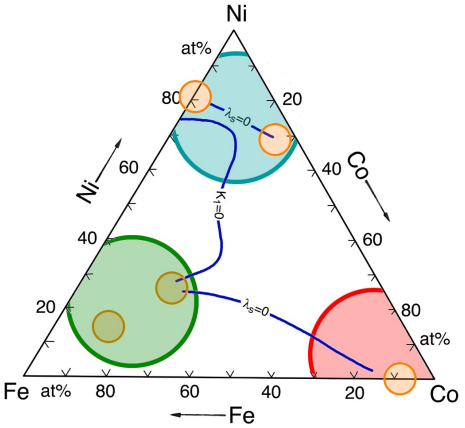
A. Makino, et al., *Mat.Trans. JIM* 36 (1995) 924

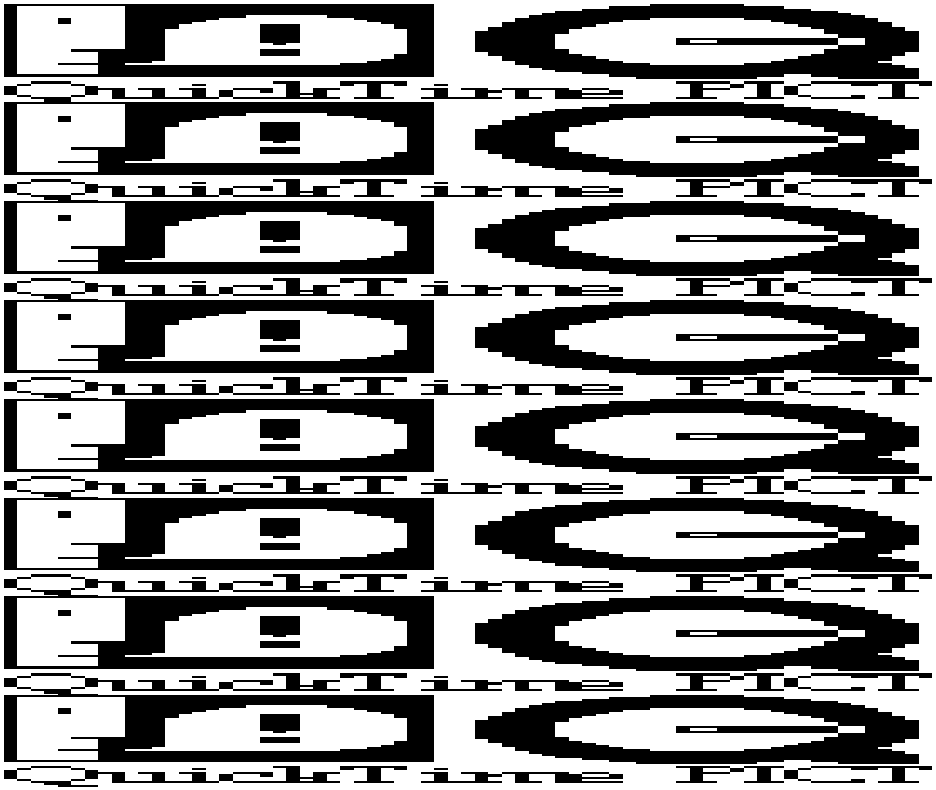


Low Magnetostriction Coefficient

- (Ni, Co, Fe)-based nanocrystalline
  - $\mu_0 M_s$ = 0.78 T
  - λ_s < 1 ppm
- Metglas 2714A Co-based
  - $\mu_0 M_s$ = 0.57 T
  - λ_s < 1 ppm
- 40% increase in M_s over equivalent amorphous alloy

High Temperature Alloys





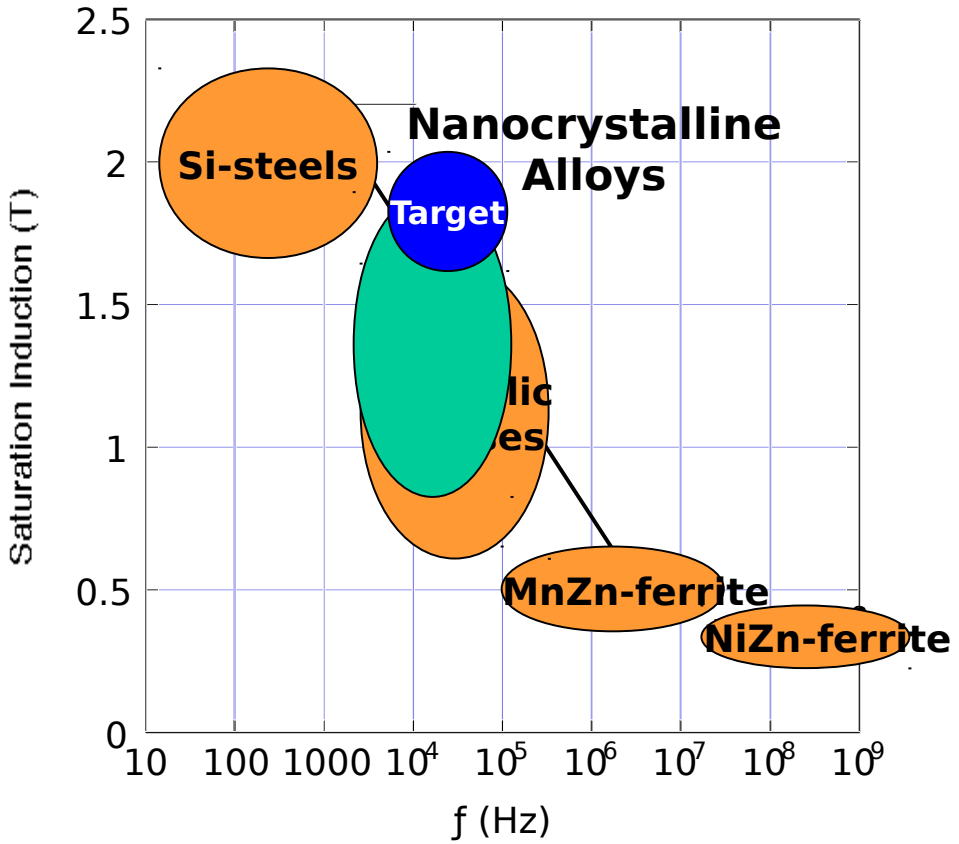
- (Co, Fe)-based (550°C for 1 hr)
  - $\mu_0 M_s$ = 1.57 T
  - T_c >> 600°C
  - λ_s = 11 ppm
- Metglas 2605SA1 Fe-based
  - $\mu_0 M_s$ = 1.56 T
  - T_c = 395 °C
  - λ_s = 27 ppm

Summary

Comparisons are made to Metglasses™

- *Magnetization*—14% increase in M_s (1.77 T) with a 50% reduction in λ_s
- *Magnetostriction*— < 1 ppm with a 40% increase in Ms
- *High temperature*— Tc >> 600 ºC, Ms=1.57 T, and a 50% reduction in λ_s

Materials Choices Based on Low Loss Performance



Challenges to technology insertion

After optimal anneal materials are ***brittle***

- difficult to form toroids
- suffer from microcracks that reduce permeability

Optimization of alloy composition have not been fully competed

- electrical resistivity (ac losses)
- permeability

Looking for industrial partners to scale up proces

Team NRL
Matt Willard
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